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A SIGHTABILITY MODEL FOR BIGHORN SHEEP IN CANYON HABITATS

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Abstract: Visibility bias (failure to observe all animals) encountered during aerial surveys produces biased estimates of population parameters. Factors affecting visibility during helicopter surveys of bighorn sheep (*Ovis canadensis*) have not been quantified. We measured visibility bias for helicopter surveys of bighorn sheep in southwestern Idaho. Visibility was influenced ($P < 0.05$) by activity, habitat, sex composition of groups, light condition, position of sheep relative to the helicopter, and topographic position but not by group size ($P = 0.781$). Multivariate regression indicated that activity ($P < 0.001$) and habitat ($P < 0.002$) variables were the most important factors affecting visibility. A sightability model was developed to estimate bighorn population and composition parameters from data collected during helicopter surveys. We conducted 12 surveys in southwestern Idaho. The estimated population observed during helicopter surveys ranged from 51.7 to 78.1% and averaged 67.1% (CV = 10.6%). Confidence intervals for population estimates ranged from 16.4 to 22.9% and averaged 18.5% (CV = 16.0%) of the population estimate. We recommend correcting survey data for visibility bias to estimate bighorn sheep population parameters.

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Key words: Aerial survey, bighorn sheep, helicopter, Idaho, *Ovis canadensis*, population estimates, sightability, visibility bias.

Bighorn sheep are normally found in steep, rugged terrain, characterized by poor or limited human access (Geist 1971). These factors limit use of ground or fixed-wing aircraft surveys to gather population data over extensive areas. Consequently, helicopters have frequently been used for bighorn surveys and have become the survey tool of choice for many management agencies. Bighorn sheep population estimates, herd composition, and distribution data are most often collected with helicopter surveys (Thompson and Baker 1981, Bodie et al. 1990, Neal et al. 1993). The ability to fly at slow speeds (<10 km/hr), hover, and access narrow canyons enables a closer approach and more intensive observation than possible during fixed-wing surveys.

Visibility bias affected aerial survey estimates for elk (*Cervus elaphus*) (Samuel et al. 1987), mule deer (*Odocoileus hemionus*) (Ackerman 1988), Dall's sheep (*Ovis dalli*) (McDonald et al. 1990), bighorn sheep (Neal et al. 1993), and other species (LeResche and Rausch 1974; Caughley 1974, 1977; Pollock and Kendall 1987). Failure to correct for visibility bias results in an underestimate of population size, narrow variance estimates, and may produce population estimates and confidence intervals that do not overlap true population size (Steinhorst and Samuel 1989). Samuel et al. (1987) developed a sightability model that corrected for visibility bias during elk helicopter surveys. Group size and percent canopy cover were variables that most affected sightability of elk. The model increases precision of elk population estimates, and Unsworth et al. (1990) reported that the model decreased bias when compared with surveys not corrected for visibility bias.

McDonald et al. (1990) used a double-sample survey using a fixed-wing/helicopter technique to estimate visibility bias of Dall's sheep. The number of sheep in the group was the only variable that affected observability. They did not estimate visibility bias for groups missed by both surveys or measure the bias associated with incorrectly re-identifying groups of sheep. Our objectives were to use techniques described by Samuel et al. (1987) to develop a sightability model and sampling procedures for bighorn sheep, and evaluate use of this sightability mod-

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el to estimate population size and composition of bighorn sheep in southwestern Idaho.

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STUDY AREA

The Little Jacks Creek (LJC) study area was located in Owyhee County in southwestern Idaho and was 277 km². Most of this area was a rolling plateau ranging from 1,372 to 1,848 m in elevation. The plateau was divided by Little Jacks and Shoofly creeks. Canyon walls along these drainages were composed of rhyolitic and basaltic materials and averaged 300 m high. Canyon walls were typically steplike, with tiers of cliffs separated by small benches with shallow soils.

Vegetation consisted of sagebrush (*Artemesia* spp.) communities. The few, widely scattered trees were primarily western juniper (*Juniperus occidentals*) and mountain mahogany (*Cercocarpus ledifolius*). Willows (*Salix* spp.) occurred in riparian areas. On the high plateau, Wyoming big sagebrush (*A. tridentata wyomingensis*) dominated moderately deep soils, whereas low sagebrush (*A. arbuscula*) dominated shallow and stony soils. Rabbitbrush (*Chrysothamnus* spp.) and prickly pear (*Opuntia* spp.) occurred on disturbed sites. Common grasses included bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg bluegrass (*Poa sandbergii*), and bottlebrush squirreltail (*Sitanion hystrix*). Plant names are from Hironaka et al. (1983).

The East Fork of the Owyhee River (EFO) area abutted the southern border of the LJC drainage and extended from the Duck Valley Indian Reservation on the east to the Oregon state line on the west within Owyhee County, Idaho. Vegetation and topography were similar to that of the LJC area except that the western portion of the area on the north side of the Owyhee River had stands of western juniper and mountain mahogany. Major tributaries were Battle and Deep creeks.

METHODS

We captured bighorns from a helicopter either by drive netting (Beasom et al. 1980) or hand-held net gun (Barrett et al. 1982). Captures occurred on the LJC area during October–January 1987–91. Bighorns were aged, sexed, fitted with radio collars, and released. The number of sheep with functional radio collars varied between 15 and 33 during the project.

We divided the LJC area into 10 units, 12–46 km² ($\bar{x}$ = 24.3, SE = 3.12). We drew borders along barriers to bighorn movement and along definable topographic features such as drainage bottoms or ridgetops. We assigned units to 1 of 2 strata on the basis of the number of sheep expected to be observed in the unit during a helicopter survey (strata 1, >19 sheep; strata 2, <20 sheep). We used 2 methods to assign units to strata on the basis of densities observed during past ground and aerial surveys (Bodie et al. 1990) and from 6 aerial surveys conducted during this study. We surveyed sheep during June, because group sizes were large, bighorn use of the plateau was greatest, most lambing was complete, and ewes and lambs had formed nursery groups reducing the potential for the helicopter survey to disrupt lambing activities (Bodie et al., unpubl. data).

We located sheep from fixed-wing aircraft in the morning immediately prior (<30 min) to sightability surveys. We recorded map locations of all radio-collared bighorns and radioed them to a ground team leader. We located ground observers before dawn in areas with the potential to have sheep in view during the survey. The ground team leader relocated observers to maximize the number of bighorn groups under observation during the survey and assigned to the helicopter aerial survey team the number and order of units to sample. Ground observers used radio telemetry equipment, binoculars, and/or spotting scopes to locate sheep and recorded sheep behavior as the helicopter approached. The helicopter survey team was not aware of ground observer locations or the number or location of bighorn groups in view of ground observers.

Sightability Flights

We conducted a total of 14 helicopter flights during June 1989–91 to assess sightability of sheep. Sightability flights were separated by ≥7 days to reduce animal stress. A Bell Jet Ranger

III helicopter with 2 experienced observers, in the left front and right rear seats, and a pilot in the right front seat was flown systematically at 35–45 km/hour 30–60 m aboveground on 100-m contours over the survey area. Doors nearest the observers were removed to increase visibility. Search patterns typically started at the drainage bottom and progressed upslope until the plateau was reached. The plateau was flown in a strip pattern at 200-m intervals. We did not conduct survey flights when winds exceeded 25 km/hour or during rain.

Upon sighting a group of sheep the pilot would point the nose of the helicopter at the sheep, and the primary observer would assign a number to the group and inform the ground observers by 2-way radio. Ground and helicopter observers counted and classified each group, recorded the map location, and noted presence or absence of radio-collared sheep. For each group, we recorded the following independent variables: slope position (canyon bottom, lower third, middle third, upper third, above canyon), habitat (flats, cliffs, dissected cliffs, caves, benches, riparian), light condition (sun, shade, cloud cover), helicopter position relative to the group (above, even, below), activity (moving, not moving, bedded), sex (M, F, mixed group), and time of day. Ground observers also recorded this information for groups missed by the helicopter survey.

Ground and helicopter observers compared data within 48 hours of the sightability flight to determine which groups were observed or missed by the helicopter crew. Bighorn groups known to be in the surveyed unit but not visible to ground observers were not included in the dataset. We used all groups observed and missed by the helicopter crew to develop a sightability model (Samuel 1984).

We evaluated effects of independent variables on visibility bias, using a likelihood-ratio Chi-square test for univariate analyses (Dixon 1981) and stepwise logistic regression (Dixon 1981) for multivariate analyses. We also used forward and backward stepwise logistic regressions to develop models of visibility bias (Samuel et al. 1987) to estimate sheep population size and composition (Steinhorst and Samuel 1989, Samuel et al. 1992). We calculated correction factors for each combination of independent variables. We obtained correction factors for each group by inverting the estimated sighting probability (Samuel 1984, Steinhorst and Samuel 1989). We estimated population size and composition parameters by applying the appropriate correction factor to each group observed during a survey and then summed these estimates for each study area.

Population Surveys

We conducted a population survey of all units during June 1989–94 in the LJC area and during June 1990–94 in the EFO area. We conducted a second survey in June 1994 in response to an apparent population decline between 1992 and 1994. Helicopter survey techniques were similar to those used during sightability flights except that all known or suspected areas of bighorn use were surveyed and the helicopter was held 75–100 m from lamb-ewe groups in steep cliffs during classification to preclude accidental injury to sheep. Observers used binoculars to correctly classify these groups. We determined distance moved by bighorns during surveys by measuring the straight-line distance between map locations of radio-collared animals recorded during presurvey fixed-wing and helicopter surveys.

We added the bighorn sightability model to the program AERIAL SURVEY (Unsworth et al. 1991), which estimated population and composition parameters for LJC and EFO population surveys. We used the Chi-square test (Sauer and Williams 1989) with program CONTRAST (Hines and Sauer 1989) to test for differences within estimators among years and a 1-tailed Z-test (Zar 1984) to compare lamb : ewe (lambs/100 ewes) and ram : ewe (rams/100 ewes) ratios within and among years.

RESULTS

Sightability Model

We determined sightability of 123 groups of sheep during 14 flights (Table 1). The helicopter survey located 75 (61%) of the groups observed by ground crews during sightability flights. Activity, habitat, topographic position, sex composition of group, helicopter position, and light condition were related to sightability (Table 1). Moving groups of sheep were twice as likely as stationary groups to be seen by the helicopter crew. Sheep on cliffs, talus, or benches, or in caves were less visible than those on flats or open slopes. Groups found on the middle or upper one-third of canyons were less visible than groups on the bottom, lower third, or above canyons.

Table 1. Effects of 7 independent variables on visibility (% observed) of 123 bighorn sheep groups in southwestern Idaho, 1989–91.

Variable	No. of groups Seen	Missed	Visibility	χ^2	df	*P*-value[a]
Activity				16.99	1	<0.001
Moving	56	18	0.76			
Not moving	19	30	0.39			
Habitat				14.47	3	<0.002
Cliffs and talus	10	6	0.62			
Benches	12	13	0.48			
Dissected cliffs, caves	23	24	0.49			
Flats/open slopes	30	5	0.86			
Topographic position[b]				13.94	3	<0.006
Bottom, lower third	6	2	0.75			
Middle third	16	15	0.52			
Upper third	28	27	0.51			
Above canyon	25	4	0.86			
Group size				2.47	5	0.781
1	10	8	0.56			
2	15	9	0.62			
3	10	6	0.62			
4–6	18	14	0.56			
7–14	17	6	0.74			
15–40	5	5	0.50			
Sex[c]				6.11	1	0.013
Lambs-ewes	37	35	0.51			
Rams	31	11	0.74			
Mixed	3	1	0.75			
Helicopter position[d]				7.99	2	0.018
Above sheep	47	24	0.62			
Below sheep	14	18	0.44			
Level with sheep	12	2	0.86			
Light condition				7.13	2	0.028
In sun	40	14	0.74			
In shade	24	24	0.50			
Overcast	11	10	0.52			

[a] Probability that visibility of categories differs within a variable by likelihood-ratio Chi-square test.
[b] Group position within or above canyon.
[c] Sex not known for 5 groups, rams and mixed categories combined for Chi-square test.
[d] Helicopter position not known for 6 groups.

Lamb-ewe groups were less visible than ram or mixed-sex groups. Sheep in direct sunlight were more visible than shaded groups or sheep observed on overcast days, and sightability was highest for groups at or above, rather than below, the altitude of the helicopter. Group size was not related to sightability.

Stepwise logistic regression indicated that activity and habitat were primary factors affecting sightability and produced the model with the best fit (log-likelihood ratio, $P < 0.001$), when habitats were combined into 2 categories, flats/open slopes or canyons (including cliffs, dissected cliffs, caves, talus, and benches) and activity into moving or not moving (standing and bedded). Additional habitat or activity categories did not improve the model ($P > 0.10$). When we considered the influence of activity and habitat, adding other variables did not improve (log-likelihood ratio test, $P > 0.10$) prediction of visibility.

The final model for predicting probability of sighting a group of sheep (p) was

$$p = \frac{e^x}{1 + e^x},$$

where $x = 0.7149 - 1.433x_1 + 1.541x_2$, e^x = natural logarithm of x (base e), and

$$x_1 = \begin{cases} 0, & \text{if moving} \\ 1, & \text{if not moving} \end{cases}$$

$$x_2 = \begin{cases} 1, & \text{if habitat = flats, open slopes} \\ 0, & \text{if habitat = canyons.} \end{cases}$$

The model estimated sighting probabilities as 0.91 for groups of sheep moving on flat/open

Table 2. Observed and sightability model estimates of bighorn sheep population parameters from helicopter surveys in Little Jacks Creek area, southwestern Idaho, ±90% confidence interval in parentheses, 1989–94.

	Observed					Model estimates[a]				
Year	Rams	Ewes	Total	R:E[b]	L:E[c]	Rams	Ewes	Total	R:E	L:E
1989	53	105	203	50	41	91A	213A	393A	43A	39A
						(29)	(61)	(90)	(18)	(16)
1990	87	99	232	88	47	155A	157A	381A	99A	44A
						(47)	(34)	(73)	(47)	(20)
1991	80	99	241	81	56	112A	163A	376A	69A	56B
						(22)	(40)	(67)	(21)	(20)
1992	71	81	194	88	52	95A	138A	308A	70A	55B
						(20)	(29)	(51)	(21)	(18)
1993	84	136	251	62	23	104A	193A	341A	54A	23C
						(22)	(46)	(63)	(18)	(09)
1994	57	107	204	53	38	85A	146A	287A	59A	38A
						(25)	(30)	(54)	(19)	(06)

[a] Parameter estimates within columns followed by different letters differ for population estimates ($P < 0.10$), Chi-square test (Sauer and Williams 1989) and ratios ($P < 0.05$), Z-test (Zar 1984).
[b] R:E = rams/100 ewes.
[c] L:E = lambs/100 ewes.

slope habitats, 0.70 for not moving on flat/open slope habitats, 0.67 for moving on canyon habitats, and 0.33 for not moving on canyon habitats.

Population Surveys

We conducted 6 population surveys of the LJC area during June 1989–94. Model estimates for population size did not differ among years ($\chi^2 = 6.69$, 5 df, $P = 0.245$). The estimated population that was observed during surveys ranged from 51.7 to 73.6% and averaged 66.2% (CV = 12.6%). The estimated lamb : ewe ratio differed among years ($\chi^2 = 59.49$, 1 df, $P < 0.001$) (Table 2).

We flew 6 population surveys in the EFO area in 1990–94 (Table 3). The sightability model estimates of population size differed among years ($\chi^2 = 49.65$, 5 df, $P < 0.001$). The number of sheep observed increased 6% between 1992 and 1993, but the model estimated a population decrease of 18% during the same period ($\chi^2 = 3.55$, 1 df, $P = 0.046$) and a further decrease between 1993 and 1994 ($\chi^2 = 8.48$, 1 df, $P = 0.004$). The estimated population observed varied from 58.0 to 78.0% and averaged 68.1% (CV = 9.2%).

The percentage of ewes observed with lambs in open/flat habitats averaged 12.5% ($n = 212$) for LJC and 16.3% ($n = 334$) for EFO areas compared with 61.7% ($n = 1,130$) and 55.2% ($n = 1,523$), respectively, for canyon habitats for all years. Lamb : ewe (Z = 0.043, $P = 0.519$) and ram : ewe (Z = 0.300, $P = 0.618$) ratios did not differ between surveys in the EFO area in 1994.

Radio-collared sheep ($n = 40$) moved an average of 2.1 ± 0.26 km between fixed-wing and helicopter survey locations. Average distance moved by ewes ($n = 21$, 1.72 ± 0.28 km) and rams ($n = 19$, 2.42 ± 0.43 km) did not differ ($t = 1.365$, 31 df, $P = 0.183$). Sixty percent ($n = 40$) of radio-collared sheep were located in a different unit between presurvey fixed-wing and helicopter flights. Predictions of bighorn sheep numbers observed in units were incorrect 44% of the time ($n = 57$). When we stratified units on the observed average density of each unit during the initial 6 LJC surveys, 40% ($n = 57$) were incorrectly classified.

DISCUSSION

Sightability Model

Activity and habitat were the most useful factors for predicting sightability of bighorn sheep during June helicopter surveys. Ackerman (1988) found that activity influenced sightability of mule deer. No observations of bedded bighorns occurred during helicopter surveys, and this type of activity would be unlikely due to the reaction of bighorns to helicopter survey disturbance. Therefore, we reduced activity categories to moving or not moving.

Vegetational cover has been important in several studies that examined visibility bias in ungulate surveys (Samuel et al. 1987, Ackerman 1988, McDonald et al. 1990). Bighorns are an exception, because vegetation is normally not used for thermal regulation or concealment. Lit-

Table 3. Observed and sightability model estimates of bighorn sheep population parameters from helicopter sightability surveys in the Owyhee River area, southwestern Idaho, ±90% confidence interval in parentheses, 1990–94.

	Observed					Model estimates[a]				
Year	Rams	Ewes	Total	R:E[b]	L:E[c]	Rams	Ewes	Total	R:E	L:E
1990	80	373	699	21	56	116A (40)	555A (105)	1,033A (179)	21A (08)	55A (15)
1991	174	400	753	43	44	204B (32)	615A (128)	1,111A (200)	33B (09)	47A (16)
1992	164	322	628	51	44	246B (81)	542A (117)	1,041A (205)	45C (18)	46A (15)
1993	182	406	669	45	20	215B (39)	530A (104)	858B (141)	41BC (11)	21B (08)
1994a[d]	93	179	347	52	41	126A (33)	256B (71)	486B (102)	49BC (19)	39A (08)
1994b	96	177	336	54	36	143A (36)	276B (71)	532B (119)	52BC (19)	41A (09)

[a] Parameter estimates within columns followed by different letters differ for population estimates ($P < 0.10$), Chi-square test (Sauer and Williams 1989) and ratios ($P < 0.05$), Z-test (Zar 1984).
[b] R:E = rams/100 ewes.
[c] L:E = lambs/100 ewes.
[d] 2 surveys were conducted in Jun 1994.

tle vegetation of sufficient height to cover more than the legs of an adult sheep exists on the study area. Bighorns use topographic and habitat features in a manner similar to elk and deer use of vegetation for concealment and thermal regulation (Geist 1971). Consequently, habitat features influenced sightability of bighorns. Bighorns were less observable when on terraces, highly dissected cliffs, or in caves than when on open cliffs or flats. Habitat classified into 2 categories, flats/open slopes or canyons (including cliffs, dissected cliffs, caves, thalus, and benches), produced the sightability model with the best fit.

Group size is an important factor influencing sightability (Cook and Martin 1974, Cook and Jacobson 1979, Samuel and Pollock 1981) and is a factor for elk (Samuel et al. 1987), mule deer (Ackerman 1988), and Dall's sheep (McDonald et al. 1990) aerial surveys. Group size did not affect sightability for bighorn sheep. Moving and not moving groups of sheep in flat/open slope habitats and moving sheep in canyon habitats have high sightability (91, 70, and 67%, respectively). High levels of sightability may mask effects of group size on visibility bias. Disturbed sheep form compact groups and act collectively. The increase in visible surface area of a large compact group over a smaller group may not be sufficient to measurably improve sightability. The 95% confidence intervals on sighting probabilities for group sizes were wide and ranged from 0.50 ± 0.31 for groups of 15–40 sheep ($n = 10$) to 0.56 ± 0.17 for groups of 4–6 sheep ($n = 32$). Increased sample size may indicate differences in sighting probabilities among group sizes.

Several factors, including light condition, helicopter position, sex composition of group, and topographic position, influenced sightability but did not improve predictive capability when included in the model. These factors apparently interrelate with activity and habitat variables. For example, most flat/open slope habitats were outside canyons in the topographic position category flats, and all canyon habitats were in the remaining topographic categories (bottom, lower third, middle third, and upper third). Ram groups were more likely to use habitats with greater visibility (flat/open slope), whereas ewes used habitats with less visibility (canyons).

Sightability was highest when bighorn groups were even with the helicopter, least when above, and intermediate when below the helicopter. Bighorns respond less strongly to disturbances when they are above the source of disturbance than when level with or below the disturbance (Hicks and Elder 1979, MacArthur et al. 1979). Also, observer ability to see downward is restricted by the aircraft bottom, and this may reduce sightability of groups below the helicopter.

Assumptions associated with the sightability model include the population is demographically closed during the survey, double counting does not occur, and survey techniques and weather conditions are the same as those used to develop the model. The latter assumption means the use of experienced observers, and helicopter type, flight path, speed, altitude aboveground, and season of year are not different. Bighorn behavior is also assumed the same as the behavior of bighorns used to develop the model, contrast of ground to sheep is the same between areas, and habitats have the same sightability probabilities.

Bighorns sometimes avoid helicopters by moving to adjacent units or moving out of canyons and across the flats to units already surveyed. Bighorn avoidance of the survey may violate the assumption of a closed population, causing the model to underestimate population numbers.

Generally, sightability models for ungulates have been based on repeat observations of radio-collared animals. Repeated observation of a small sample of animals can produce a model with reported precision smaller than the true precision. We minimized repeat observations by using groups as the sample unit instead of radio-collared animals.

Population Surveys

Little information is available on sighting probabilities for bighorns. Consequently, comparisons of sighting probabilities measured in our study area with those of other bighorn populations are limited. The mean sighting probability for bighorn ewes of 0.57 (SE = 0.03) estimated for population surveys in our study is similar to that reported by Neal et al. (1993) using a mark-resight method to estimate an individual mean sighting probability of 0.58 (SE = 0.2) for bighorn sheep ewes in Colorado.

The number of sheep observed increased for LJC and EFO in 1993 compared with 1992. A large population increase is unlikely because immigration for the LJC population is low (Bodie et al., unpubl. data), 1992–93 snow depths were 160% of normal, and the 1993 lamb : ewe ratios were <50% of 1992 levels. Our sightability model indicated that population declined in the EFO area and was not different in the LJC area between 1992 and 1993. The observed increases appeared to be due to a higher proportion of groups using habitats with high sighting probabilities (flat/open slopes) in 1993 than in 1992.

Our bighorn sightability model generally corrected observed ram : ewe ratios downward, whereas elk sightability models generally correct bull : cow ratios upward (Samuel et al. 1992). Rams were more likely to use habitats where sightability was greatest (flats/open slopes), while ewes with young lambs used areas near escape cover (canyons) during June. Bull elk groups typically used closed canopy cover more than did cow-calf groups during winter surveys. Data not corrected for visibility bias may overestimate ram : ewe ratios. Ram : ewe ratios increased and varied less as the study progressed, due in part to improved helicopter search techniques (to reduce bighorn avoidance of surveys) and better information on ram distribution.

Lamb : ewe ratios were similar before and after we applied sightability corrections. Ewes and their lambs are closely associated during June and have similar sighting probabilities. Lamb : ewe ratios were lower for groups using flat/open slope habitats than for groups using canyon habitats and may reflect differences in immature and mature ewe use of habitat. Lamb : ewe ratios were 50% lower in 1993 than in 1992 or 1994, but the proportion of ewes using flat/open slope or canyon habitats did not differ among years. Consequently, observed lamb : ewe ratios were not biased by differences in sightability. Bighorns, usually lamb-ewe groups, on dissected cliffs were sometimes difficult to approach for classification. A bias in successfully classifying 1 age-sex group over another can decrease the accuracy of corrected lamb : ewe and ram : ewe ratios, and estimates of ram, ewe, and lamb numbers, but not of population estimates.

Samuel et al. (1987) recommended using stratified random sampling on the basis of expected unit densities to reduce costs and increase precision over simple random sampling or total area sampling during sightability surveys. This procedure apportions survey effort to units on the basis of the number of animals estimated to be in the unit (a greater no. of units with large no. of animals are sampled than are units with few animals). Assignment of units to incorrect strata lowers precision and can produce estimates with less precision than simple random sampling (Steinhorst and Samuel 1989). Bleich et al. (1990) reported that desert bighorns (*O. C. mexicana*) responded to helicopter survey-caused disturbance by moving long distances and were likely to move from surveyed units to adjacent units violating the assumption of closure, and these movements could produce underestimates of population numbers. Long flight distances, movements between sampling units, and our inability to predict the density of sheep observed in sampling units during helicopter surveys precluded use of random or stratified random sampling for sightability surveys in our study area.

MANAGEMENT IMPLICATIONS

Our bighorn sightability model can provide wildlife managers a means to estimate population size and levels of precision for bighorn sheep in canyon habitats. This model has not been validated, and sightability surveys of bighorn populations of known numbers are needed to assess the model's correction of visibility bias. The model is not recommended where timbered habitats are used by bighorns.

An inability to predict sampling unit densities and movement of sheep among sampling units can create problems in sample designs for bighorn helicopter surveys. Our data suggest that it may be difficult to meet the assumption that sampling units have closed populations necessary for sample designs such as random or stratified random sampling (Cochran 1963). Instead, we recommend survey designs covering the entire area, sampling with units large enough to minimize movements of animals to nonsampled areas, or delineating sample units with boundaries not likely to be crossed by disturbed bighorns (e.g., large rivers or extensive flat areas).

The precision of counts not corrected for visibility bias can be improved by selecting the time of year when sighting probabilities are high and have the least variation, standardizing survey techniques (e.g., search rate, altitude, flight paths, aircraft type, and weather conditions), and using experienced pilots (Bleich et al. 1990) and experienced observers. However, such surveys will have biased population and sex composition estimates, and detection probabilities may not be the same between surveys.

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GENERALIZED MARK-SIGHT POPULATION SIZE ESTIMATION APPLIED TO COLORADO MOOSE

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Abstract: A new procedure for constructing confidence interval estimates of population size in mark-sight experiments is presented. The method of selecting animals for marking must be equivalent to a simple random sample without replacement. Marked animals are required to be individually identifiable. The number of times animals are sighted must be independent of their mark status. The sighting process does not need to be composed of independent sighting trials or even decomposable into separate trials. Sighting probabilities can vary among individuals and can depend on such factors as group size and vegetational cover. Other methods of constructing confidence intervals in mark-sight experiments given these latter conditions have failed to achieve their stated nominal confidence level. Our confidence interval procedures are shown by simulation to have actual confidence levels close to nominal under conditions encountered in an application to a Colorado moose (*Alces alces shirasi*) population. For this population with 29 radio-collared moose and 5 helicopter sighting flights, the 90% confidence interval for the moose population size on the 1,400-km² area was 382–505.

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Population size estimation combining an initial period of animal marking followed by a period of animal sighting to determine mark status has been termed marking and sighting experiments (Arnason et al. 1991). We assume the population of interest is closed (Seber 1982: 4). The simple Petersen method (Seber 1982:59) is a special case of mark-sight experiments. In the Petersen method a sample of the population is selected and marked; then a second sample is selected (or observed) and examined for marks. The total number of animals sighted in the second sample divided by the proportion of the marked animals sighted in the second sample gives the Petersen estimate of population size. If the second sample is equivalent to a simple random sample without replacement then we will call it a single population sighting trial. Rice and Harder (1977) considered mark-sight experiments where the second sample consisted of k independent population sighting trials (MSIPT; mark-sight with independent population trials). A modified Petersen estimate (Seber 1982:60) of population size was calculated for each trial. Rice and Harder (1977) used the mean of the k-modified Petersen estimates as their best estimate of population size. Precision of this estimator depends on the number of marked animals, the number of sighting trials, and population size. They provided required sample